

Supplementary Information for

**Observed Weakening of the Kuroshio Driven by the East Asian
Winter Monsoon under Ongoing Climate Warming**

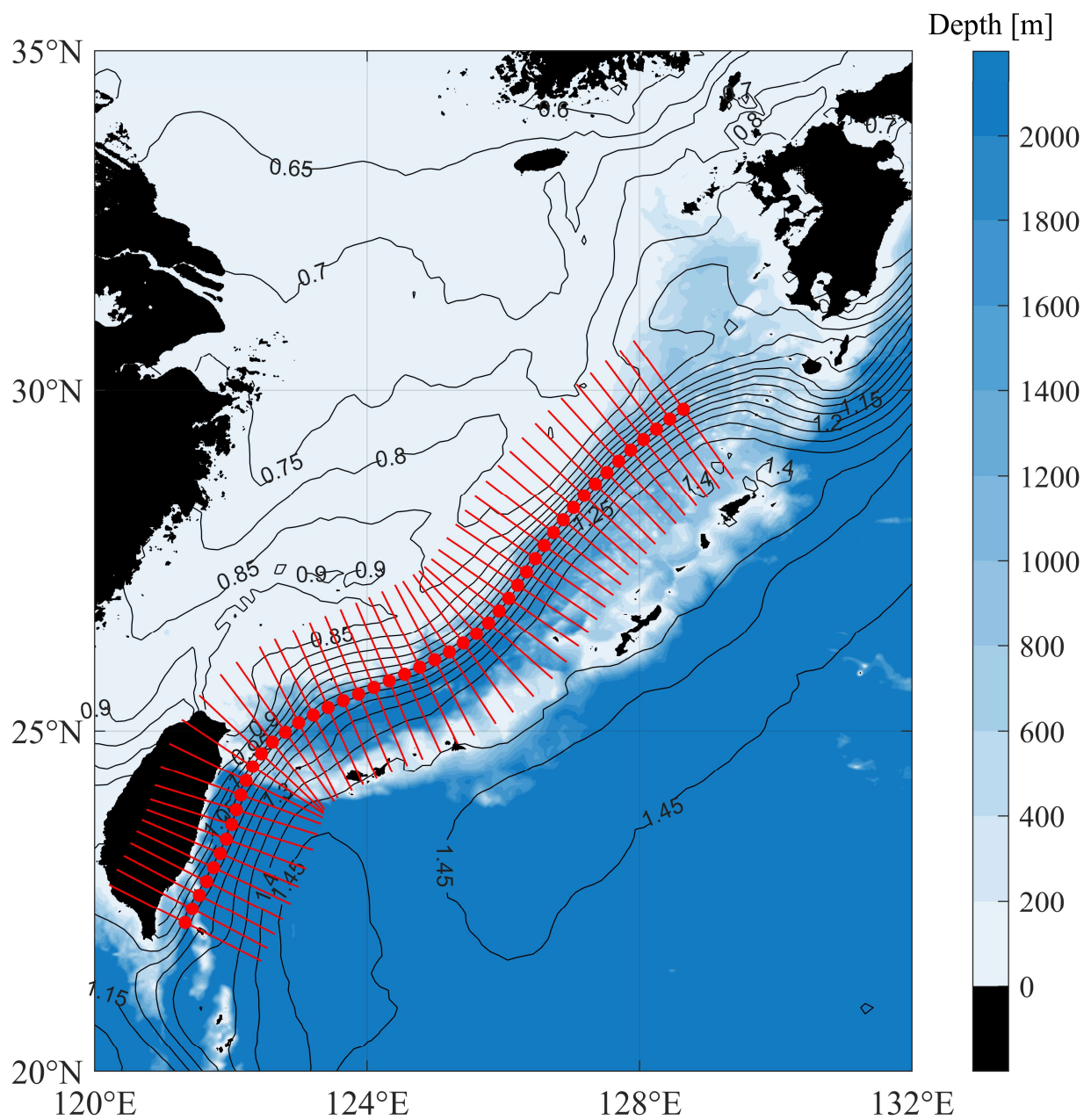
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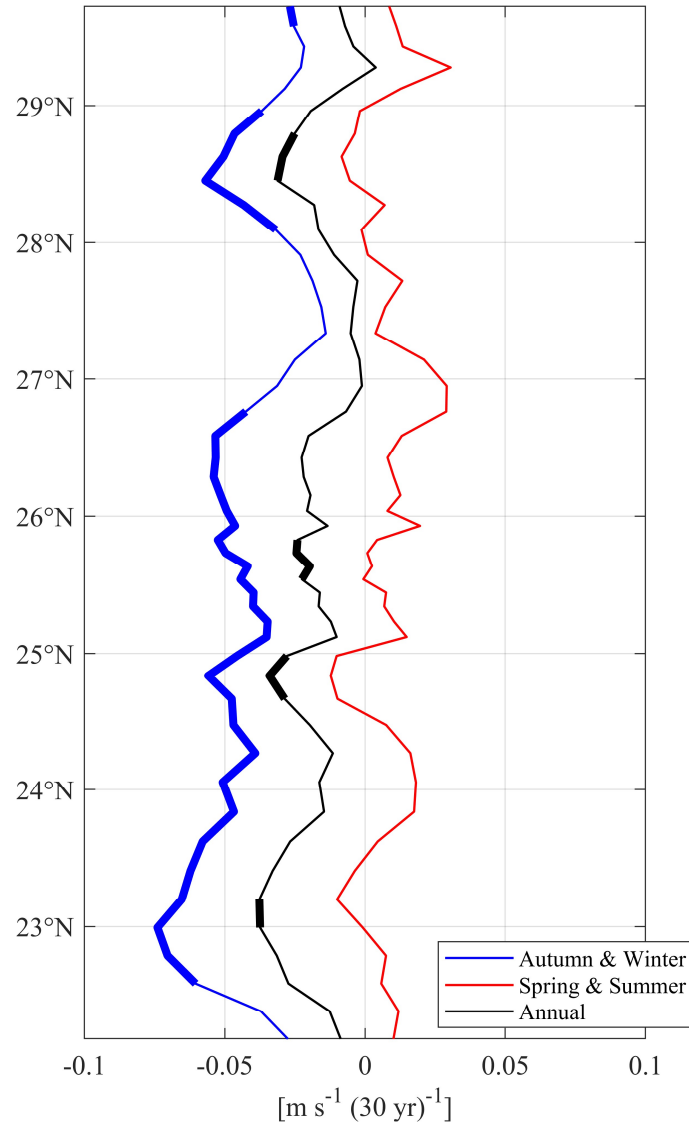
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Supplementary Fig. 1 to Fig. 8



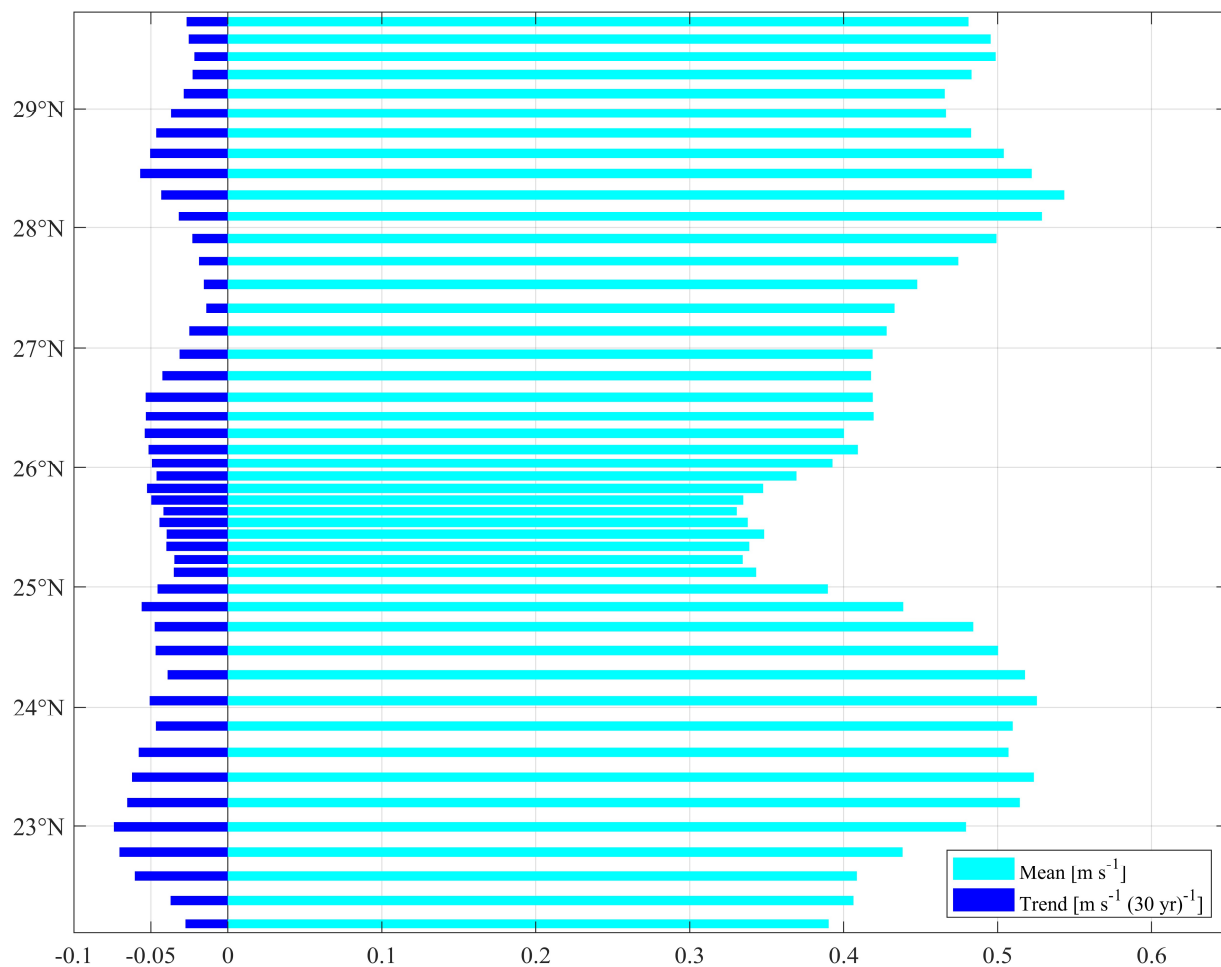
Supplementary Fig. 1. Cross-sections along the Kuroshio stream coordinate from ETW to the ECS.

Red lines denote the sections used to compute the cross-sectionally averaged SGV along the Kuroshio stream coordinate. Black contours indicate the climatological mean SSH.



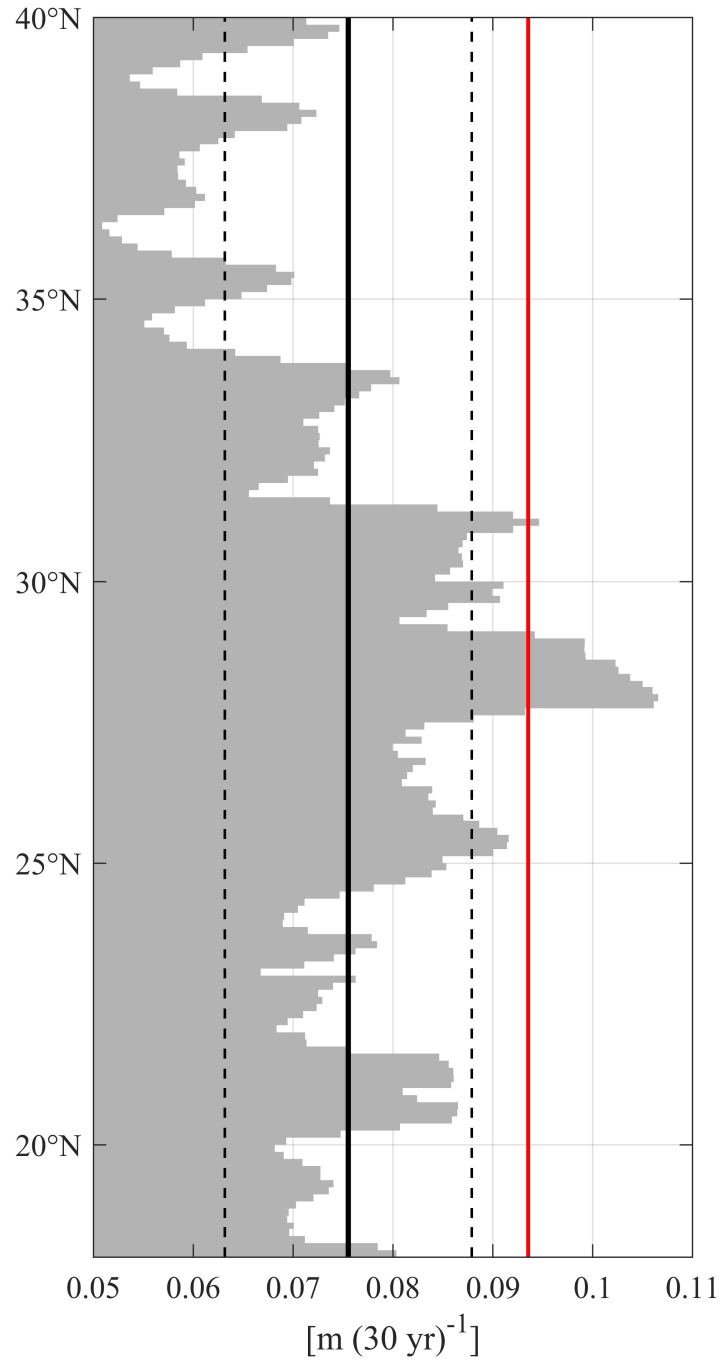
Supplementary Fig. 2. Trends in cross-sectionally averaged SGV along the Kuroshio stream coordinate.

Black line denotes trends in the annually averaged cross-sectional SGV. Blue and red lines are the same as the black line, but for those averaged in autumn–winter and spring–summer, respectively. Trends significant at the 90% confidence level are shown by the thick lines.



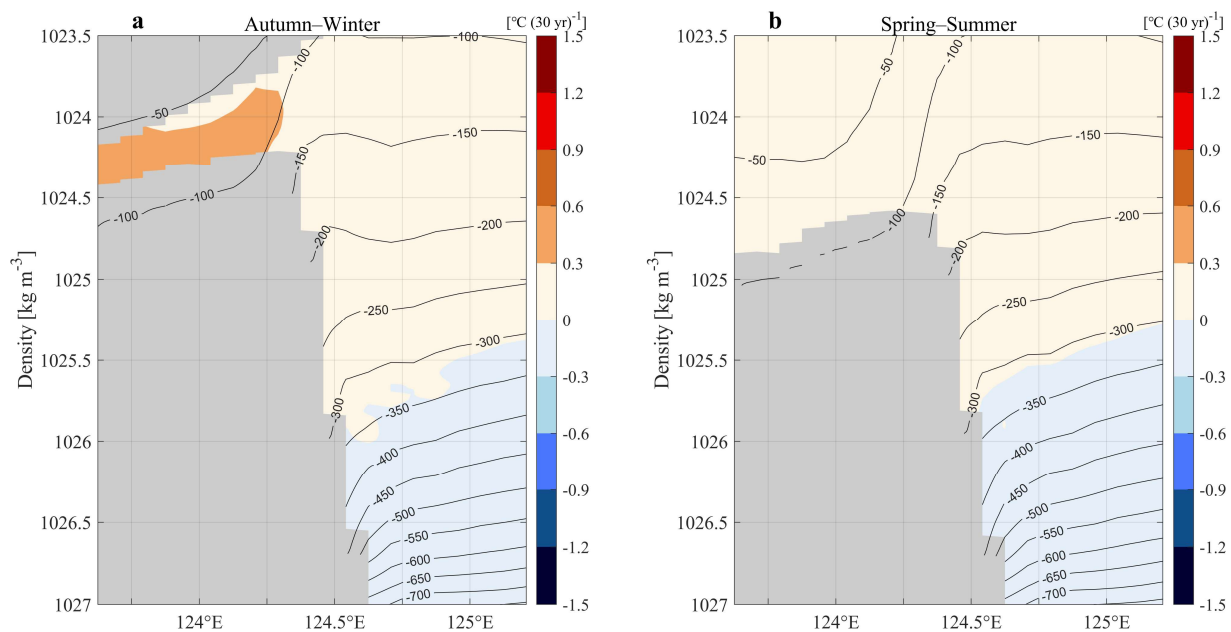
Supplementary Fig. 3. Mean and trends of cross-sectionally averaged SGV along the Kuroshio stream coordinate in autumn–winter.

The mean ratio of the trends to the corresponding mean values is $10 \pm 4\%$.



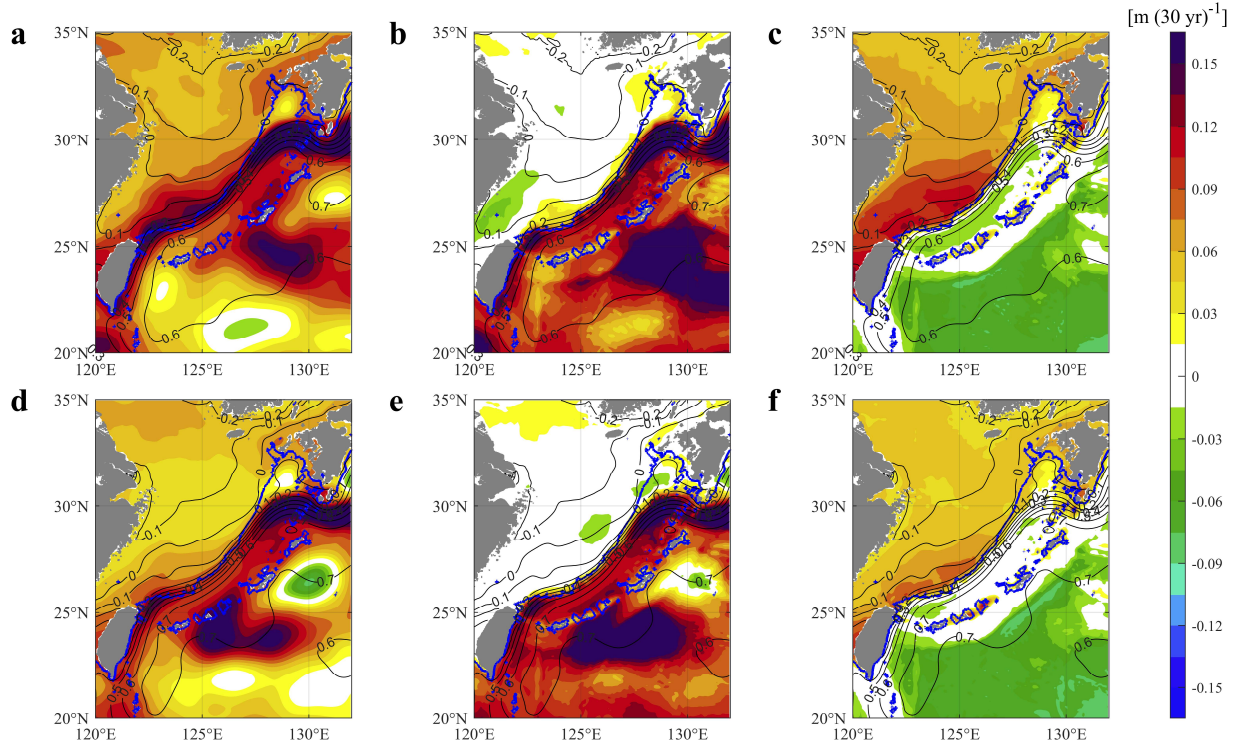
Supplementary Fig. 4. Comparison of subtropical eastern boundary SSH trends in the North Pacific with the global-mean SSH trend.

Gray bars denote the subtropical eastern boundary SSH trends in the North Pacific. The corresponding mean value is indicated by the solid black line, while the mean $\pm$ standard deviation is indicated by the dashed black lines. The global-mean SSH trend is shown by the red line.



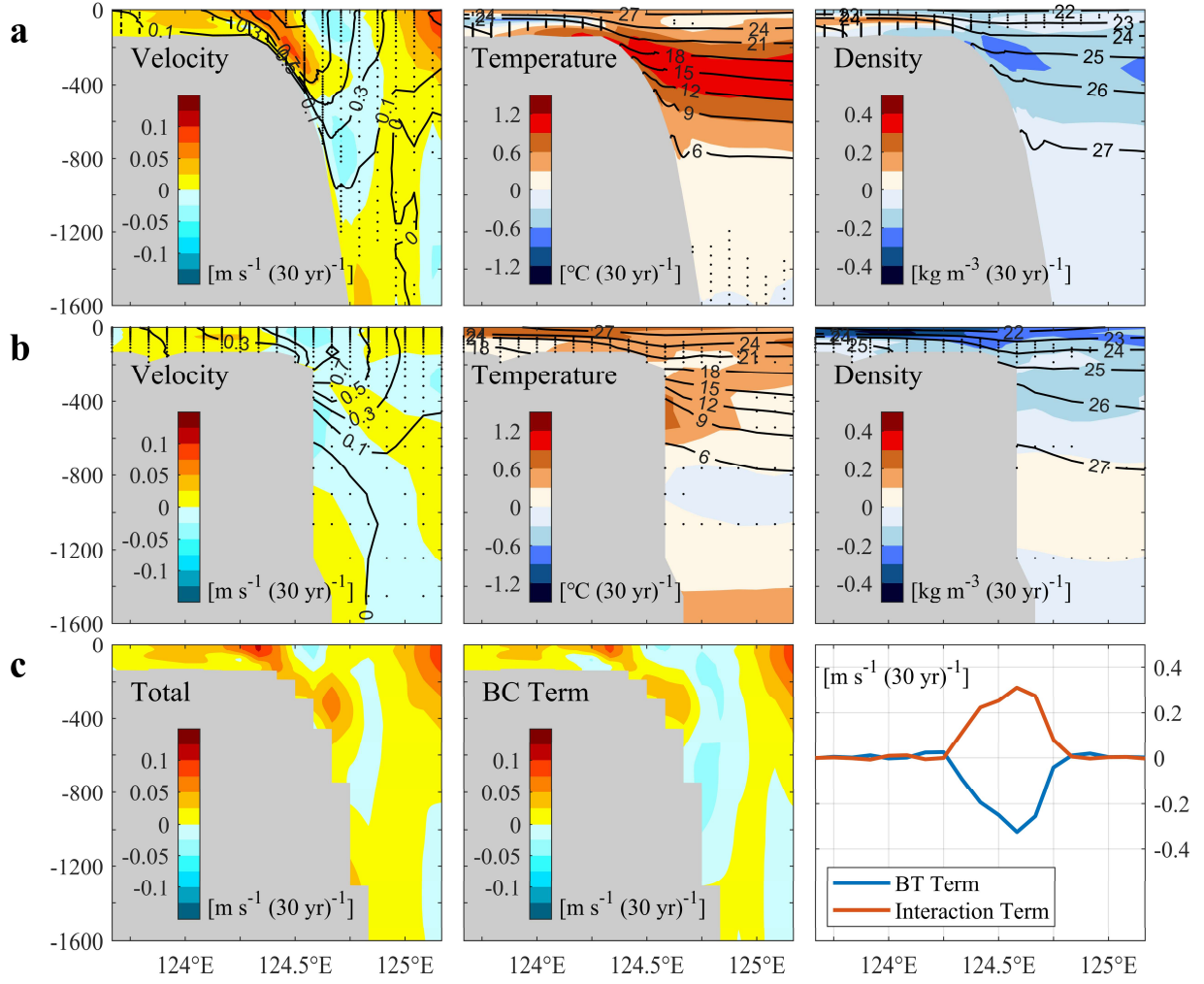
Supplementary Fig. 5. Vertical structures of temperature trends over the past three decades based on JCOPE2M, dominated by advective processes in the Kuroshio region.

Colors denote temperature trends on isopycnal coordinates for (a) autumn–winter and (b) spring–summer. Contours indicate the climatological mean depth of isopycnal surface for the corresponding season.



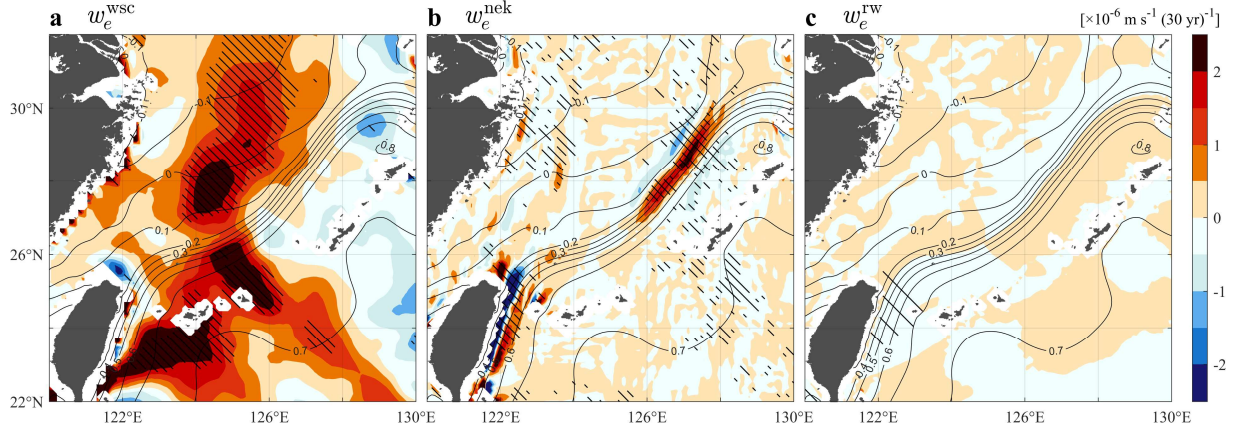
Supplementary Fig. 6. Trends in SSH and its components over the past three decades based on JCOPE2M.

(a–c) Trends in (a) total SSH (η), (b) steric SSH (η_s) and (c) SSH related to local ocean mass (η_m) during autumn–winter. η_m is estimated as the difference between η and η_s , such that $\eta_m = \eta - \eta_s$. (d–f) Same as (a–c), but for spring–summer. Contours denote the climatological η for the corresponding season. Blue line denotes the 200-m isobath.



Supplementary Fig. 7. Vertical structures of the Kuroshio trends in spring–summer over the past three decades.

(a, b) Vertical structures of the trends in cross-sectional velocity (left), temperature (middle), and density (right; σ_t) during spring–summer, based on (a) JCOPE2M and (b) GLORYS; the cross-section location is indicated in Fig.3, a and b. Stippled areas indicate regions where trends are insignificant at the 90% confidence level. Contours denote the climatological mean for the corresponding variables. (c) Decomposition of the cross-sectional geostrophic velocity for spring–summer based on Eq. (8) in Methods using JCOPE2M. The total term (left) equals the sum of the baroclinic (middle), barotropic (right), and bottom-density–topography interaction (right) terms.



Supplementary Fig. 8. Ekman-pumping-induced vertical velocity trends in spring–summer over the past three decades.

Trends in vertical velocity during spring–summer induced by local wind forcing through (a) WSC-related Ekman pumping (w_e^{WSC}), (b) nonlinear Ekman pumping (w_e^{NEK}), and (c) relative-wind Ekman pumping (w_e^{RW}), calculated from Eq. (10) in Methods. Contours denote the climatological mean SSH during autumn–winter derived from JCOPE2M. Hatched areas indicate regions where trends exceed the 90% confidence level.